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LOW CARBON MATERIALS MANAGEMENT: A CASE STUDY FOR THE CLEMSON UNIVERSITY NET ZERO ENERGY HOUSE PROJECT

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ABSTRACT

Materials management in the construction process is a method of controlling resources for a project. This includes the materials selection process, purchasing process, delivery process, and waste management process, which all constitute the materials management plan for the project. While many research projects suggest efforts to reduce overall project cost by managing materials more efficiently, few focus on materials management from a sustainability perspective. In 2009, the U.S. Environmental Protection Agency published a report on *Sustainable Materials Management: The Road Ahead*, which details the importance of sustainable materials management practices. This project directly addresses a need defined in the EPA's report, the need to identify materials management practices for sustainable projects.

The design of a net-zero energy residential building at Clemson University provided for a unique opportunity to study materials management practices and methods for sustainable projects. Specifically, the research applied life-cycle assessment to calculate the estimated changes in the case study project's carbon footprint that are associated with common materials management. Findings from the case study were used to identify transferrable insights for a range of projects.

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The author also recognizes the indispensable help of two undergraduate assistants, Gabrielle Conlon and Megan Milam, who researched carbon emissions data and created infographs.

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CHAPTER ONE

INTRODUCTION AND BACKGROUND

Introduction

Sustainable development, or "development that meets the needs of the present without compromising the ability of future generations to meet their own needs [1]," is increasingly important to designers, not only in the construction industry but also in other areas. A nationwide consciousness of sustainability exists at the individual level; cumulative responses from the 1972-2006 General Social Survey (GSS) indicate that just around half of the respondents agreed that protecting the environment was of utmost importance, but only around a third thought that the American government was successful in protecting the environment [2]. From 1985 until 2008, the Gallup poll indicated that respondents felt that the protection of the environment should be given priority over economic growth [3]. However, a corporate consciousness of sustainability developed only in the last fifteen years [4].

In June of 2009, the United States Environmental Protection Agency published a report calling for nation-wide research and development to focus on sustainability in construction and other industries [5]. Recent research by the Construction Industry Institute (CII) in materials management finds that a materials management plan can positively influence supplier performance, labor productivity, and cash flow savings over the life of a construction project [7**]. To date, the focus has been on the economic sustainability of the project.

The Organization for Economic Co-operation and Development (OECD) held a workshop on sustainable materials management in Seoul, Korea, in November 2005. The members of the workshop developed a working definition of sustainable materials management, which takes into account international thoughts and ideas on what the term suggests and should include. The participants defined sustainable materials management as

> *"an approach to promote sustainable materials use, integrating actions targeted at reducing negative environmental impacts and preserving natural capital throughout the life-cycle of materials, taking into account economic efficiency and social equity* [16].*"*

Sustainable materials management extends the systems boundary for analysis of the sustainability of a project. This project fulfills a portion of the EPA's request and augments the CII research by providing an introduction to and outlines of low carbon materials management practices for the construction industry. The materials management practices developed focuses on "reducing negative environmental impacts," per the OECD workshop definition.

Clemson University has begun a research project focused on building a Net Zero Energy Home on campus. A Net Zero Energy building is one which uses renewable energy products and technologies to result in an annual energy contribution to the power grid which is equal to or greater than the energy use for the building [6]. This materials management research will focus on providing for the Clemson Net Zero Energy House (NZEH) project a usable materials management guideline which should reduce the carbon emissions for the project in the planning stages of construction. The materials management guideline will be referenced when the house is built. Calculations will be done to determine the amount of carbon emission reduction possible with the sustainable materials management guidelines and program, and then the guidelines will be adapted to be applicable to other new construction projects.

This project has found that using a plan which focuses on materials selection can decrease the carbon emissions of a construction project. Carbon emissions for typical construction materials are available through resources like BRE (formally the Building Research Establishment) and the National Institute of Standards and Technology's Building for Environment and Economic Sustainability (BEES) program. Using these carbon emissions data, designers can determine the emissions impact of each material required for a project. Knowing the individual materials impacts will allow the designer to make materials selection choices to reduce carbon emissions for the project.

Typical Materials Management Practices

In 1999, The Construction Industry Institute (CII) published a set of guidelines to help contractors and others in the construction industry develop procurement and materials management systems. These guidelines constitute the current practices for materials management in the industry. The CII research group identified several projects which used materials management systems, and compared the outcomes with similar projects which did not use a materials management system. Their research showed significant reductions in bulk surplus, risk, management manpower, and site storage;

improvements in supplier performance, project schedules, and craft labor productivity; and cash flow savings [7]. Even a few of these would seem to be reason enough for a company to implement a materials management plan, and many companies have done so. These management systems, however, do not take into account environmental and societal impacts of the materials selection and delivery process.

A typical materials management system is a tool developed by companies which sets in writing the planning and communications plan for the materials process of a project. Considerations such as division of responsibilities, labor considerations, schedule and cost requirements, preferred materials sources, purchasing and expediting processes, and warehousing space are considerations for such a system.

This system is typically translated into a piece of database software with a file structure that supports static and dynamic material input files. This database contains not only material and supplier information, but also can contain purchase information, delivery information, and quality inspection information. The purpose of such a system is to streamline the materials management process to keep companies more organized, and to prevent mistakes like bulk order surplus and material availability issues [8].

Sustainable Design Overview

Introduction to Sustainable Design

Broadly, sustainable design is design which meets the Bruntland Commission's definition of sustainable development. Life cycle analysis is one tool for analyzing the sustainability of a design. These life cycle analyses often contain calculations of either embodied energy of materials or the carbon footprint of materials. This section will define life cycle analysis, embodied energy, and carbon footprint, and seek to describe the calculations thereof.

Embodied Energy, Life Cycle Analysis, and Carbon Footprint

Buildings generally require energy in three main phases: the embodied energy of the materials of the building, the operating energy of the building over its lifespan, and the energy required to demolish and/or recycle the building [9]. The exact definition of embodied energy varies according to paper and author [10]. Generally, the embodied energy of a building is the total of the amount of energy used to produce each material needed for the building and the energy required to actually construct the building.

A life cycle analysis of a material or structure looks at the energy, cost, and any other inputs for the entirety of a product's lifespan: from raw material extraction through the manufacturing phase to the delivery, use, and disposal of the product, including all transportation between phases [11]. Each of these phases has associated carbon emission impacts on the surrounding air, water, and land. The combination of all of these carbon emissions is known as the carbon footprint of the material. Calculations for the embodied energy and the carbon footprint of a building can be tedious, but are necessary to complete an accurate life cycle analysis of the building.

Sustainable Residential Design

Passive Solar Design

In 1978 Bruce Anderson and Charles Michal defined passive solar design to be "architectural features, components, and/or assemblages thereof which make use of the natural transfer of solar-generated thermal energy…for the purpose of water heating, space heating, and/or space cooling [12]." At the time of their writing, passive solar design was uncommon in the U.S. and largely ignored by major research groups and industry. In the last 30 years, there has been increased recognition of the value of designing structures to take advantage of passive solar design concepts [13]. Passive solar designs usually involve designing a structure in consideration of direct solar gain, where light and heat from the sun entering the building is stored in thermal masses in the building (walls, flooring, or other masses) and released throughout the cooler parts of the day [14]. Climate has a large impact on passive solar design, because homes must be designed to take highest advantage of light or heat, depending on the climate needs of the area. In the Southeastern United States, for example, controls like trees and roof overhangs can be used to limit solar gain in the summertime, when the heat is unnecessary, but maximize solar gain in the winter. The design of the Clemson Net-Zero Energy house uses theories of passive solar design to take advantage of the energy efficiencies achievable through such design practices.

Net-Zero Energy Design

Pless and Torcellini have broken Net-Zero Energy buildings into four categories: net-zero site energy, net-zero source energy, net-zero energy costs, and net-zero emissions [15]. The definitions vary in system boundaries: at the site, at the source, at cost, and at carbon emissions. Each of these definitions boils down to a building which produces at least as much energy as it uses over the course of the year. The Clemson Net-Zero Energy House will be net-zero site energy when active technologies are added to the building.

Clemson Net-Zero Energy House

The Clemson Net Zero Energy House is a research program committed to designing and building an affordable low-energy house adaptable to the specific climatic concerns of South Carolina. The NZEH is a residential structure designed by architecture students here at the University to take advantage of passive design strategies. The final product will be a showcase of contemporary architectural design, with a familiar feel which invites the average homeowner to come in and experience what can be done with forethought in architectural design and planning to achieve a low-energy home from natural materials at an affordable cost. The design for the house does not require a particular site, making the house ideal for adapting to any site around South Carolina, and will be *active-ready*, meaning the homeowner can decide to add active energy-gaining technologies (i.e. photovoltaics) to bring the house to *net-zero* status: producing at least as much energy as it uses.

Sustainable Materials Management

Bringing Sustainability to Materials Management

Current sustainable development tends to focus on LEED standards, as evidenced by growing numbers of organizations which require all new construction to be LEED-certified, including Clemson University and the United States federal government [17]. These LEED credits can include materials selection criteria, but are largely focused on design and construction methods or improvements. A project which is pursuing LEED certification can get up to six points through materials selection: one for recycled content, two for material reuse, one for rapidly renewable materials, and one for certified wood. Above these six, there is one extra point available for a large percentage of reused materials. LEED prescribes only two points, however, to the selection of local materials, which they define to be materials from a source within 500 miles of the project site [18]. This rating system does not seem to emphasize sustainable materials management practices.

The United States' consumption of non-renewable resources has grown from 59% in 1900 to an alarming 94% in 1995 [19]. Eventually, these resource reserves will cease to exist. The text *Materials and the Environment*, by Michael F. Ashby, describes in detail the concept of a reserve as compared to a resource base. A reserve is the amount of a particular resource which is currently technologically and economically feasible to extract. A resource base is the total amount of the resource available in the world [20]. As prospecting technologies and materials use increases, the resource base diminishes. This can only occur for so long with a nonrenewable resource before the resource base is used in its entirety [20]. Sustainable materials management must have a focus on renewable resources as much as sustainable materials. A traditional materials management plan, with priority given in materials selection to renewable and sustainable materials, is the focus of a sustainable materials management system.

Low Carbon Materials Management for the NZEH

The low carbon materials management plan for the Clemson NZEH will incorporate the considerations from the CII's Materials Management Handbook, and will focus on using local, renewable, and sustainable material. A comparison will be developed between the sustainable plan and a typical materials management plan which takes into account carbon emission reductions achieved through the sustainable plan by calculating the carbon footprint for the materials chosen.

Moving Ahead

Normal materials management approaches, designed for the economic benefit of the companies employing them, are not sufficient to address sustainable issues with regards to the environmental or societal impacts of materials selected. One focus in sustainable materials management is given to renewable materials and developing life cycle analyses of all the materials involved in a project. True sustainability requires addressing all parts of the life cycle of a project, for the same reason that one sustainable building does not make a community sustainable; sustainability is a thought-process and behavior more than a simple design concept. The focus must be not only on using recycled materials, but using renewable resources. In the coming years, sustainable materials management will become more and more important as we continue to deplete our reserves of nonrenewable resources. Materials management has a global impact.

CHAPTER TWO

CARBON EMISSIONS AND COST CALCULATIONS

Introduction

Total carbon emissions are one measure of the sustainability of a project. Because sustainability is such a broad, subjective concept, increasing the "sustainability" of a project can be a difficult task. Estimating the carbon emissions for a project gives the project leader an objective measure from which to compare material alternatives. Reducing carbon emissions, however, is only one aspect of sustainable construction. Designers must also take into consideration resilience, social impact, and cost considerations. Several companies, including the National Institute of Standards and Technology, BRE, the Edinburgh Centre for Carbon Management, and the Athena Institute, have online databases of carbon emissions data for construction materials which are available to interested researchers or laymen. From these databases, a general idea of the carbon emissions for a project can be calculated as part of a life cycle analysis for the project; knowing which materials have the largest impact can determine for a project leader where to spend money for carbon reductions.

This research is designed to investigate whether a proper materials management plan, including materials selection process, can reduce carbon emissions *before the project is ever constructed.* To examine this idea, the researcher collected a database of carbon emissions data for construction materials from which to make smart, sustainable choices. From this database, material choices were made, and their associated carbon emissions were calculated. These total emissions numbers were compared to show whether materials management related to material selection impacts the final sustainability of a project.

Methodology

In order to develop some relevant measure of carbon emissions for a comparison between traditional and sustainable materials choices, several choices had to be made. First, focusing on every material necessary for building construction is impractical. Therefore, the researcher decided to focus on several large groups of materials – foundation, interior walls, flooring, insulation, exterior walls, and roofing. The researcher identified several databases which contain carbon emissions data for appropriate construction materials, including BRE, BEES, ECCM, and ATHENA. The researcher looked up in each database typical construction materials for each category, and recorded the carbon emissions measure for each for one unit of the material. The researcher converted the emissions data to units of square or cubic meters, depending on applicability to the material, for overall comparison. The tables below (Tables 2.1 – 2.6) show the collections of materials with associated carbon emissions, including the identification for each of the database from which the number was pulled.

Table 2.1, Carbon Emissions for Selected Materials, Foundation [21, 22]

Materials	Material (Sub-Type)	Source	Amount	CO_2 [Kg]
Solid Concrete	Portland Cement	BEES	1 m^3	146.6
	50% Lafarge New Cement	BEES	1 m^3	114.1
	20% Fly Ash Cement	BEES	1 m^3	131.7
	10% Limestone Cement	BEES	1 m^3	143.7
	Lafarge Silica Fume Cement	BEES	1 m^3	214
	50% Slag Cement	BEES	1 m^3	112.7
	IP Concrete	BEES	1 m^3	115.5
Suspended Concrete	Pre-stressed Concrete	BRE	1 m^2	58
	Reinforced Concrete	BRE	1 m^2	110
Suspended Timber	OS Board	BRE	1 m^2	21
	Chip Board	BRE	1 m^2	26

Table 2.2, Carbon Emissions for Selected Materials, Interior Walls

Materials	**Material (Sub-Type)**	**Source**	**Amount**	**CO_2 [Kg]**
Steel	Generic	BEES	1 m^2	5.8
Untreated Wood	Generic	BEES	1 m^2	2.1
	Plasterboard	BRE	1 m^2	15
Treated Wood	Generic	BEES	1 m^2	3.3
	Glazed Hardwood	BRE	1 m^2	45
Concrete	Aircrete	BRE	1 m^3	196.9
	With Plasterboard	BRE	1 m^3	315
	Precast Panel	BRE	1 m^3	721.8
Brick	With Plaster	BRE	1 m^2	47
	With Plasteboard	BRE	1 m^2	60
Aluminum	Vinyl Chipboard	BRE	1 m^2	25
Rammed Chalk/Earth	Chalk	BRE	1 m^2	12
	Earth	BRE	1 m^2	12

Table 2.3, Carbon Emissions for Selected Materials, Flooring

Materials	Material (Sub-Type)	Source	Amount	CO_2 [Kg]
Carpet	Wool Tile	BEES	1 m^2	81.6
	Wool Broadloom	BEES	1 m^2	86.4
	Nylon Tile	BEES	1 m^2	51.1
	Nylon Broadloom	BEES	1 m^2	58.4
	With Felt or Foam Underlay	BRE	1 m^2	120
	With Rubber Underlay	BRE	1 m^2	190
	Cushioned Polyvinyl Chloride	BRE	1 m^2	49
	Wool Carpet	BRE	1 m^2	220
Linoleum	Generic	BEES	1 m^2	8
	Printed Laminate	BRE	1 m^2	50
	Plain	BRE	1 m^2	40
Tile	Terrazzo	BEES	1 m^2	25.7
	Resin-Based Terrazzo	BRE	1 m^2	150
	Composite Marble	BEES	1 m^2	27.4
	Vinyl Composition	BEES	1 m^2	10.4
	Porcelain	BRE	1 m^2	51
	Quarry	BRE	1 m^2	66
	Italian Marble	BRE	1 m^2	78
	Ceramic	BRE	1 m^2	79
Wood	Solid Hardward	BRE	1 m^2	-25

Table 2.4, Carbon Emissions for Selected Materials, Insulation

Materials	Material (Sub-Type)	Source	Amount	CO_2 [Kg]
Blown Glass Wool	Density 17 kg/m^3	BRE	1 m^2	4.2
Cellular Glass	Density 165 kg/m^3	BRE	1 m^2	26
Corkboard	Density 120 kg/m^3	BRE	1 m^2	-4.7
Expanded Polystyrene	Density 30 kg/m^3	BRE	1 m^2	12
Sheep Wool	Density 25 kg/m^3	BRE	1 m^2	11
Blown Mineral Wool	R-38	BEES	1 m^2	3.9
Blown Mineral Wool	R-13	BEES	1 m^2	2.3
Fiberglass Batt	R-38	BRE	1 m^2	1.9
Fiberglass Batt	R-13	BEES	1 m^2	0.9
Blown Celluloose	R-38	BRE	1 m^2	1.9
Blown Celluloose	R-13	BEES	1 m^2	0.8
Stone Wool	Density 160 kg/m^3	BRE	1 m^2	25
Straw Bale		BRE	1 m^2	-53
Strawboard Thermal		BRE	1 m^2	-63
Blown Recycled Celluloose	Density 45 kg/m^3	BRE	1 m^2	-2.1

Table 2.5, Carbon Emissions for Selected Materials, Exterior Walls

Materials	Material (Sub-Type)	Source	Amount	CO_2 [Kg]
Brick & Mortar	Generic	BEES	1 m^2	45.2
Stucco	Generic	BEES	1 m^2	15.3
Aluminum Siding	Generic	BEES	1 m^2	10.8
Wood	Cedar Siding	BEES	1 m^2	0.6
Vinyl	Generic	BEES	1 m^2	14.2
Meteon Panels	Trespa	BEES	1 m^2	24.9
Cladding Outsulation	Dryvit EIFs	BEES	1 m^2	10.2
Virgin Fibercement		BEES	1 m^2	25.3
Insulation Siding	Progressive	BEES	1 m^2	16.2
Timber Curtain Wall	With Plasterboard	BRE	1 m^2	300
Aluminum Curtain Wall	With Plasterboard	BRE	1 m^2	310
Fibre Cement	With Steel Reinforcement	BRE	1 m^2	82
Brickwork	With Steel Framing	BRE	1 m^2	69
Brickwork	With Timber Framing	BRE	1 m^2	52
Marble Cladding	Steel Support & Plasterboard	BRE	1 m^2	170
Brick & Mortar	With Plaster	BRE	1 m^2	73
Polymeric Render System	With Plasterboard	BRE	1 m^2	98
Softwood Boarding On Battens	Rammed With Earth/Chalk	BRE	1 m^2	4.6

Table 2.6, Carbon Emissions for Selected Materials, Roofing

Materials	Material (Sub-Type)	Source	Amount	CO_2 [Kg]
Asphalt Shingles	1 Layer Felt	BEES	1 m^2	15.5
Clay Shingles	1 Layer Felt	BEES	1 m^2	19.5
Fiber Cement Shingles	Generic	BEES	1 m^2	27.5
Pitched Roof W/ Timber	Concrete Tiles	BRE	1 m^2	29
Pitched Roof W/ Timber	Photovoltaic Tiles	BRE	1 m^2	6
Pitched Roof W/ Timber	Slate	BRE	1 m^2	25
Pitched Roof W/ Timber	Steel Sheets	BRE	1 m^2	52
Pitched Roof W/ Timber	Clay Tiles	BRE	1 m^2	53
Pitched Roof W/ Steel	Concrete Tiles	BRE	1 m^2	87
Pitched Roof W/ Steel	Photovoltaic Tiles	BRE	1 m^2	49
Pitched Roof W/ Steel	Slate	BRE	1 m^2	68
Pitched Roof W/ Steel	Steel Sheets	BRE	1 m^2	71
Pitched Roof W/ Steel	Clay	BRE	1 m^2	97
Flat Roof Timber Joists	Ply Roof Membrane	BRE	1 m^2	27
Low Pitched With Steel Rafters	Composite Roof Cladding	BRE	1 m^2	110
Low Pitched With Timber Rafters	With Steel Sheets	BRE	1 m^2	48
Beam And Dense Block Deck	With Rounded Pebbles	BRE	1 m^2	180
Concrete Hollow Slab	Asphalt Roofing	BRE	1 m^2	240

The researcher chose one or two materials for each material category, estimated in their proper amounts from construction documents for the Clemson Net Zero Energy House, and recorded as a single sum of carbon emissions for the given categories. In order to compare different combinations of materials (and therefore find the combination of materials with the least carbon emissions), the researcher assumed that the sum of carbon emissions for the materials in the house *not* identified in this study were identical. This assumption allows for a comparison of emissions data without the intensive study and calculations required for a full life cycle analysis of the potential house. Further research may indicate that this full life cycle analysis is appropriate for determining the best combination of construction materials, but is irrelevant to the final purpose of this project. If material choices among these six material categories can produce significant carbon emissions savings, then materials selection for the rest of the NZEH should only add to those savings.

The researcher identified several combinations of materials to calculate total emissions, including one for typical construction material choice as identified by a civil engineering student involved with the project, one for aesthetic purposes, as identified by an architecture student involved with the project, and one which uses the material with the least carbon emissions in each category, to represent the "most sustainable" structure possible with our materials choices. The researcher also compared two houses with the same materials with materials ordered from a distance of 500 miles or less of the site and materials ordered from a distance of 50 miles or less from the site.

Table 2.7 shows the total carbon emissions for the Clemson Net Zero House with typical versus sustainable material selections. The third set, sustainable, expanded, shows two different exterior wall and floor choices; an architecture student involved with the project chose these for aesthetic purposes. As can be seen, there is a significant change in total carbon emissions – 44,000 tons CO_2 – achieved simply through material choice for these six areas of construction, even disregarding distance considerations.

Table 2.7, Carbon Emissions for Selected Materials Combinations, Method

House	Materials	Sub-category	Amount [m^2, m^3]	Total CO_2 [kg]	Total CO_2 [kg]
Typical	Foundation	PC Concrete	14.2	2,081	42,093
	Insulation	Fiberglass Batt, R-13	131.9	119	
	Interior Walls	Treated Wood, generic	131.9	435	
	Exterior Walls	Brick & Mortar	296.0	13,379	
	Flooring	Carpet with felt/foam underlay	199.3	23,913	
	Roofing	Asphalt Shingles	139.7	2,166	
Sustainable	Foundation	Concrete, 50% Slag	14.2	1,600	-2,551
	Insulation	Cork	131.9	-620	
	Interior Walls	Treated Wood, generic	131.9	435	
	Exterior Walls	Cedar Siding	296.0	178	
	Flooring	Hardwood	199.3	-4,982	
	Roofing	Pitched Roof w/ Timber, PV tiles	139.7	838	
Sustainable, Expanded	Foundation	Concrete, 50% Slag	14.2	1,600	2,072
	Insulation	Cork	131.9	-620	
	Interior Walls	Treated Wood, generic	131.9	435	
	Exterior Walls 1 (central core)	Cedar Siding	137.3	82	
	Exterior Walls 2	Vinyl Siding	158.7	2,253	
	Flooring 1 (Kitchen, Bath, etc.)	Linoleum	74.7	598	
	Flooring 2 (rest)	Hardwood	124.6	-3,114	
	Roofing	Pitched Roof w/ Timber, PV tiles	139.7	838	
Aesthetic	Foundation	Concrete 50% Slag	14.2	1,600	644
	Insulation	Cork	131.9	-620	
	Interior Walls	Treated Wood	131.9	435	
	Exterior Walls 1 (central core)	Vinyl	137.3	1,950	
	Exterior Walls 2 (rest)	Cedar Siding	158.7	95	
	Flooring 1 (Kitchen, Bath, etc.)	Solid Hardwood	74.7	-1,867	
	Flooring 2 (rest)	Solid Hardwood	124.6	-3,114	
	Roofing	Asphalt shingles	139.7	2,166	

Table 2.8 shows a comparison of carbon emissions from the Clemson Net Zero Energy House between sourcing materials within 500 miles of Clemson and sourcing materials within 50 miles of Clemson. As can be seen, a roughly 6,000 tons CO_2 difference can be achieved when materials are sourced locally. This calculation assumes all materials can be sourced locally, which may or may not be the case. Although this savings is not as extreme as those savings available due to materials selection choices, they are still significant: around 17%.

Table 2.8, Carbon Emissions for Selected Materials Combinations, Distance

House	Materials	Sub-category	Amount [m^2, m^3]	Total CO_2 [kg]	Total CO_2 [kg]
Distance: 500 mi	Foundation	Generic Portland Cement	14.2	2,802	33,399
	Insulation	Fiberglass Batt R-38	131.9	853	
	Interior Walls	Generic Treated Wood	131.9	433	
	Exterior Walls	Generic Brick and Mortar	137.3	20,376	
	Flooring 1	Generic Linoleum	74.7	597	
	Flooring 2	Carpet	124.6	6173	
	Roofing	Asphalt Shingles	139.7	2166	
Distance: 50 mi	Foundation	Generic Portland Cement	14.2	2,095	27,651
	Insulation	Fiberglass Batt R-38	131.9	788	
	Interior Walls	Generic Treated Wood	131.9	393	
	Exterior Walls	Generic Brick and Mortar	137.3	16,065	
	Flooring 1	Generic Linoleum	74.7	566	
	Flooring 2	Carpet	124.6	6,002	
	Roofing	Asphalt Shingles	139.7	1,742	

Comparison

As the tables indicate, small changes in material selection for building a house can make large environmental impacts in the area of carbon emissions. The comparison between typical materials and sustainable materials made a larger impact than researchers expected in the total emissions for the project, even with just the few categories studied.

Figure 2.1 shows the relative impacts of the material choices as relative sizes of the NZEH in the picture. The infographs in Figures 2.2 and 2.3 show some emissions equivalents for the reductions in emissions caused by changing material selection and distance, respectively.

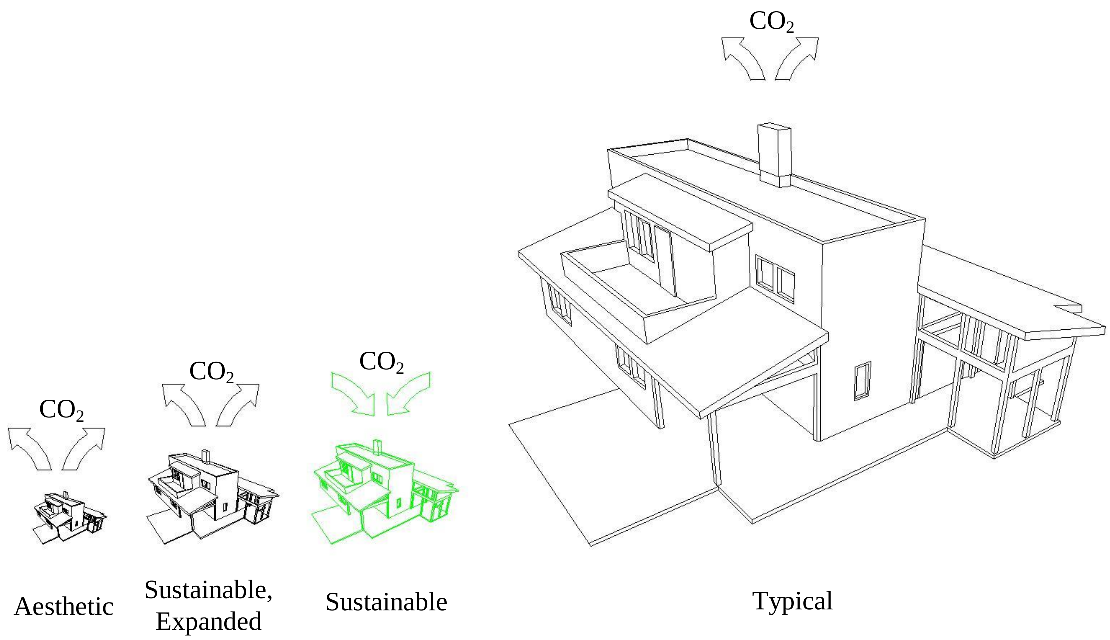

Figure 2.1, Relative Carbon Emissions for Material Selections

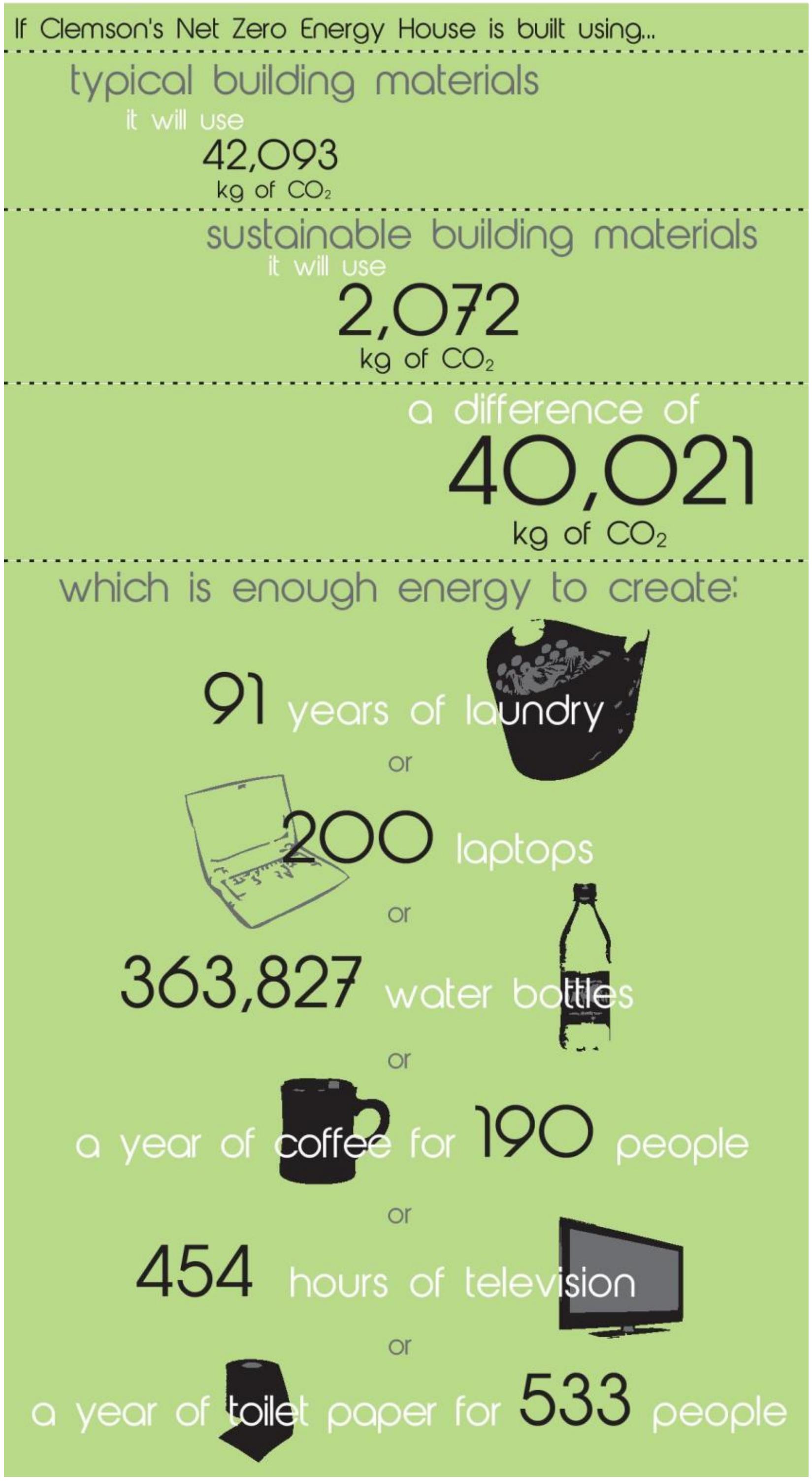

Figure 2.2, Carbon Emissions (Method) Infograph [23, 24]

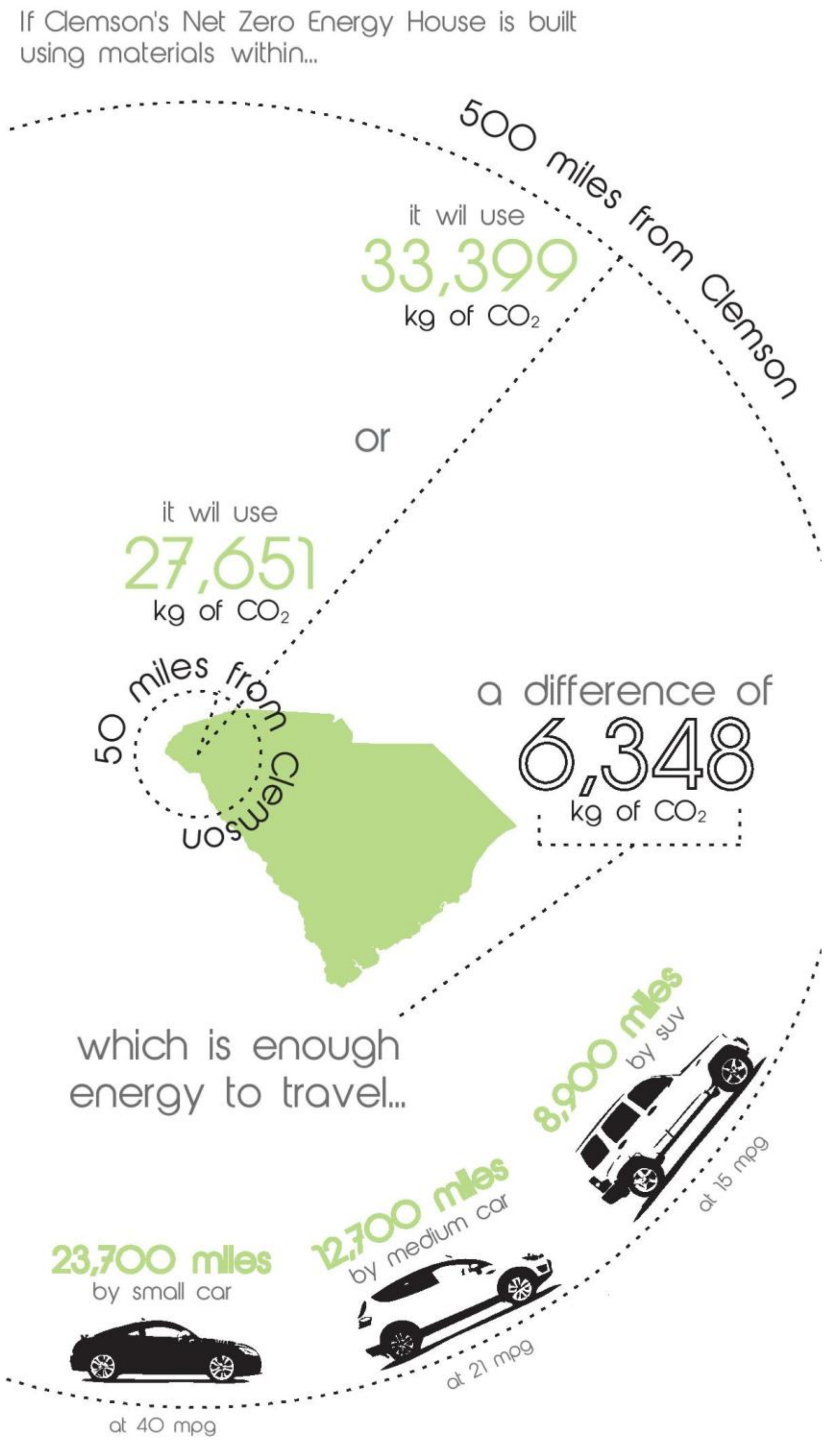

Figure 2.3, Carbon Emissions (Distance) Infograph [23, 24]

Cost Calculations

As mentioned in the introduction, carbon emissions savings are not the only consideration for sustainable construction. Cost of materials is often a prohibitive factor in choosing materials. Table 2.9 shows cost comparisons for each of the materials selections listed in Table 2.7. In some cases, the low carbon materials choices increased cost to the point of likely being cost prohibitive. Notably, however, the combination "Aesthetic" shows a *reduction* in cost. Cost savings from the use of cedar and vinyl sidings and bamboo floors over brick and carpeting more than outweighed the large increase in insulation cost. This table suggests to developers that using low carbon materials does not necessarily equate to increased cost.

Table 2.9, Cost Comparison for Selected Materials Combinations [25]

House	Materials	Sub-category	Amount [m^2, m^3]	Total Cost	Total Cost
Typical	Foundation	PC Concrete	14.2	$4,161	$27,334
	Insulation	Fiberglass Batt, R-13	131.9	$334	
	Interior Walls	Treated Wood, generic	131.9	$1,111	
	Exterior Walls	Brick & Mortar	296.0	$14,592	
	Flooring	Carpet with felt/foam underlay	199.3	$6,122	
	Roofing	Asphalt Shingles	139.7	$1,015	
Sustainable	Foundation	Concrete, 50% Slag	14.2	$4,161	$52,309
	Insulation	Cork	131.9	$10,950	
	Interior Walls	Treated Wood, generic	131.9	$1,111	
	Exterior Walls	Cedar Siding	296.0	$4,673	
	Flooring	Hardwood	199.3	$4,247	
	Roofing	Pitched Roof w/ Timber, PV tiles	139.7	$27,167	
Sustainable, Expanded	Foundation	Concrete, 50% Slag	14.2	$4,161	$51,658
	Insulation	Cork	131.9	$10,950	
	Interior Walls	Treated Wood, generic	131.9	$1,111	
	Exterior Walls 1 (central core)	Cedar Siding	137.3	$2,168	
	Exterior Walls 2	Vinyl Siding	158.7	$1,486	
	Flooring 1 (Kitchen, Bath, etc.)	Linoleum	74.7	$$1,960	
	Flooring 2 (rest)	Hardwood	124.6	$2,655	
	Roofing	Pitched Roof w/ Timber, PV tiles	139.7	$27,167	
Aesthetic	Foundation	Concrete 50% Slag	14.2	$4,161	$25,275
	Insulation	Cork	131.9	$10,950	
	Interior Walls	Treated Wood	131.9	$1,111	
	Exterior Walls 1 (central core)	Vinyl	137.3	$1,286	
	Exterior Walls 2 (rest)	Cedar Siding	158.7	$2,505	
	Flooring 1 (Kitchen, Bath, etc.)	Solid Hardwood (bamboo)	74.7	$1,592	
	Flooring 2 (rest)	Solid Hardwood (bamboo)	124.6	$2,655	
	Roofing	Asphalt shingles	139.7	$1,015	

CHAPTER THREE

MATERIALS MANAGEMENT PLAN FOR THE NET ZERO ENERGY HOUSE

Purpose

A properly developed materials management plan will include several sections, as defined by *Procurement and Materials Management: A Guide to Effective Project Execution* (*Guide*), a publication of the Construction Industry Institute in 1999. These sections, as listed in the *Guide*, are as follows: purpose [of the project], project definition, material and equipment requirements, purchasing, expediting, quality plan, logistics requirements, site material control, and automated material systems [7]. For a commercial or industrial project, this plan can become, of necessity, quite lengthy. For residential construction, considerations for several of these categories may be limited due to their relative lack of importance, especially when using typical building materials. However, any building project – commercial, residential, or industrial – will benefit from careful planning in the beginning stages to avoid complications later in the process.

The purpose of this materials management plan is to reduce the potential carbon emissions for the Clemson Net Zero Energy House project. As shown in Chapter 2 of this thesis, simply choosing materials wisely can drastically reduce the carbon emissions for a construction project. The materials researched for this analysis were typical construction materials; the new trend in sustainable materials in the building industry was not included due to lack of available emissions data. The analysis also did not take into account cost effects of material choices. However, the analysis does show that careful planning on the front end of a project can be just as effective as careful architectural design using passive and active technologies to reduce a house's environmental footprint.

The purpose of the Clemson Net Zero Energy House is to design and build an affordable, low-energy, active-ready house appropriate for the climate conditions of Clemson, South Carolina. The architects who designed the building strove to design a contemporary structure with an inviting feel – proving that environmentally-friendly houses don't have to be the cold, technology-ridden structures we portray in our minds. This materials management plan seeks to continue that proof – to show that by carefully choosing materials which are readily available to contractors, a home-owner can reduce his carbon impact, even without expensive technologies.

Project Definition

General

The Clemson Net Zero Energy House (NZEH) will be located on Clemson's main campus, with access to public transportation and biking/walking routes to academic and administrative buildings on campus. The House will achieve significant energy and water efficiency, with possible future technologies contributing to its status as a Net-Zero Energy House – one which produces over the course of a year at least as much energy as it uses.

The NZEH is a part of a Creative Inquiry project at Clemson University which includes architecture and civil engineering students and professors. The goal of the project was to develop an active-ready home for a "2 plus 2" family: two parents, two children; two adults, two elders; or four students. The NZEH will be located on Clemson's main campus, within walking and biking distance to campus as well as with reasonable access to Clemson Area Transit (CAT). The NZEH was designed to encourage sustainable living, and will hopefully be reproduced as part of the sustainability initiative at the University.

Design Considerations

Several design constraints were placed on the Creative Inquiry team who developed the NZEH. The finished plan was to be spatially optimized, climate specific, energy efficient, culturally sensitive, active-ready, and economical. In layman's terms, the house was to be reasonably sized, to include passive strategies appropriate to the Clemson area, to consume little energy, to integrate typical materials and typologies of the area, to be prepared for active technology add-ons (e.g. photovoltaic cells), and to be affordable. After several semesters of adjustment, the final plans were deemed to meet all of these standards. These plans are included in Figures 3.1 and 3.2.

Figure 3.1, Clemson NZEH, First Floor

The highlighted areas of the first floor plan are the spaces included in the "central core" of the house, where all mechanical and plumbing systems will be located, included the kitchen, bathrooms, and laundry. The extensions on this lower level include the master suite, living and dining space, as well as a bonus room.

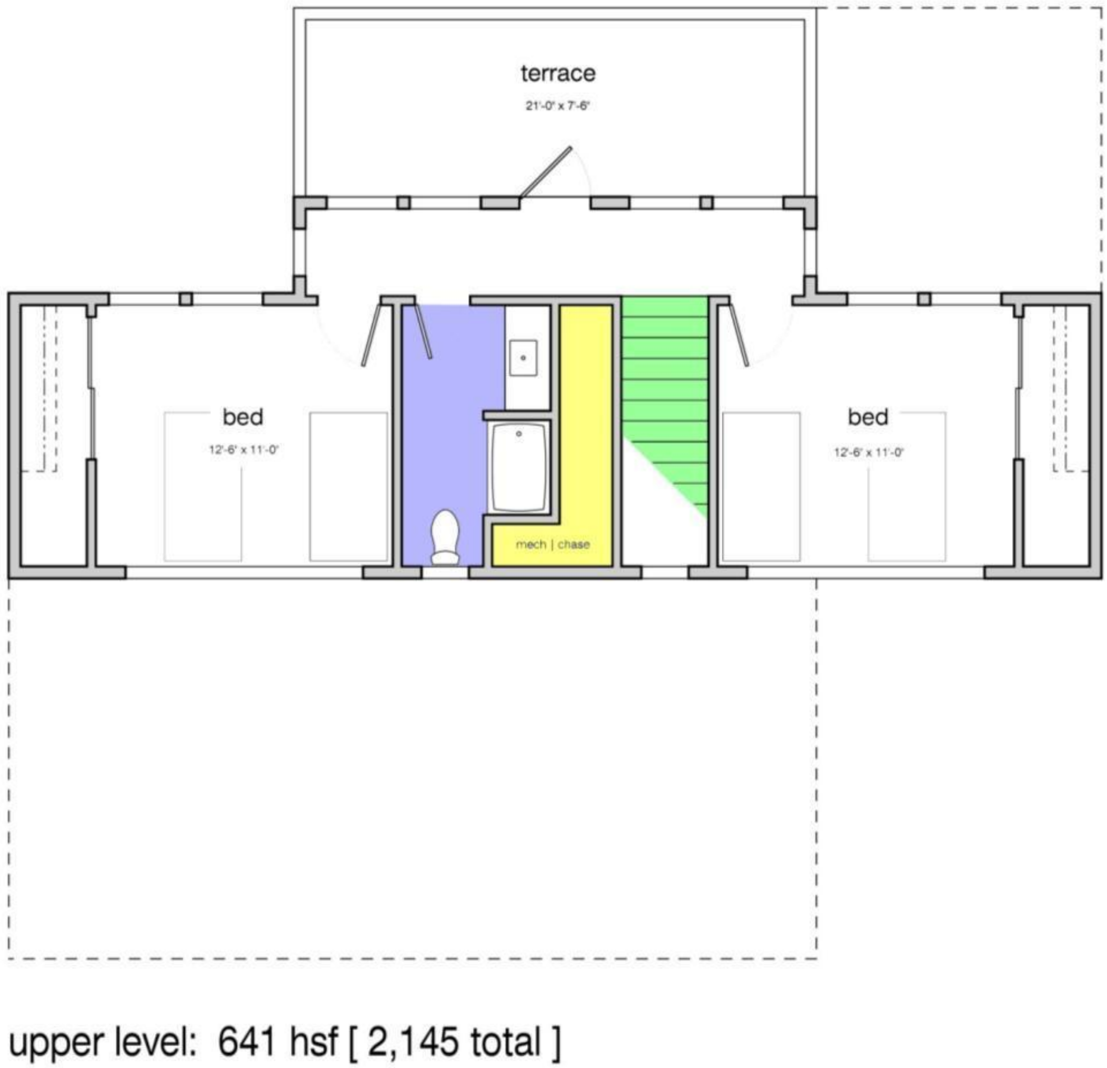

Figure 3.2, Clemson NZEH, Second Floor

The second floor of the NZEH will enclose less space than the first floor; as can be seen, only the central core of the building continues for both stories. This area will include two bedrooms and a full bath. The area above the bonus room and part of the master bedroom on the first floor will be a terrace on this floor, as can be seen in the rendering in Figure 3.3.

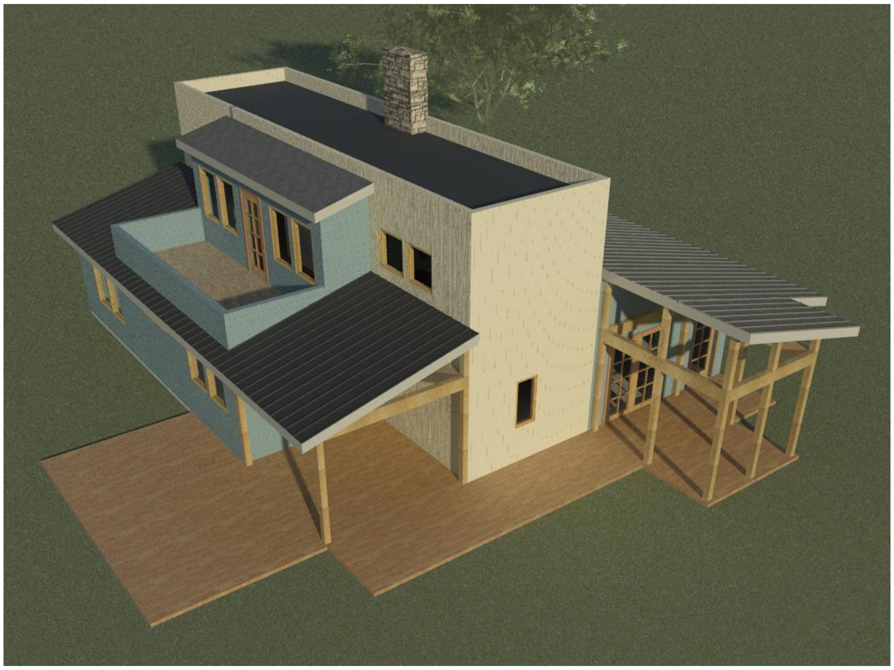

Figure 3.3, Rendering of the Clemson NZEH

A complete materials take-off for the project will be required. However, a rough estimate of the amounts of materials in several structure categories is included in Table 3.1 for reference, and should suffice for this plan.

Table 3.1, Material Requirements Estimate

Material	Amount Required [m^2, m^3]
Foundation	139.7
Insulation	131.9
Interior Walls	131.9
Exterior Walls	296.0
Flooring	199.3
Roofing	139.7

The final plans for the project do not currently specify materials choices. The Creative Inquiry group wished to leave these materials as vague as possible in order to allow future input from funding partners. This materials management plan will seek to provide materials selection recommendations for several key areas of construction, based on the carbon emissions research provided in Chapter 2 of this thesis.

Material Management Responsibilities

The general contractor will work closely with the Project representative to ensure materials are selected with reasonable respect to sustainable practices. When possible, materials will be ordered from production locations less than 500 miles from Clemson University, with a preference to materials whose entire product life cycle falls within the smallest possible radius from Clemson, South Carolina.

Material and Equipment Requirements

Definitions and Scope Requirement

A full material take-off will be required by the contractor. All materials and equipment needed for the project will be provided by the contractor.

Responsibilities

Material and equipment security will be the responsibility of the contractor.

Material Recommendations

The materials shown in Table 3.2 are recommended for use in the Clemson Net Zero Energy house, based on the carbon emissions data collected from BEES and BRE. The contractor may suggest changes based on carbon emissions, material availability, or material cost. Changes to this list must be approved by a Project Representative.

Table 3.2, Recommended Materials for the NZEH

Materials	Sub-category	Amount [m^2, m^3]	Total CO_2 [kg]
Foundation	Concrete, 50% Slag	14.2	1,600
Insulation	Cork	131.9	-620
Interior Walls	Treated Wood, generic	131. 9	435
Exterior Walls 1	Vinyl Siding	137.3	1,950
Exterior Walls 2	Cedar Siding	158.7	95
Flooring	Hardwood (bamboo)	199.3	-4,982
Roofing	Asphalt Shingles	139.7	2,166

Purchasing

General Responsibilities

Material purchases will be conducted by the contractor. When possible, materials will be ordered from production locations less than 500 miles from Clemson University, with a preference to materials whose entire product life cycle falls within the smallest possible radius from Clemson, South Carolina.

Approved Suppliers

All materials suppliers must meet University supplier standards and must be approved by the University project representative.

Quality Plan

Intro/Owner Philosophy

All materials used for this project must meet University quality standards. The contractor will be responsible for quality checks. Although the materials selection process will emphasize low carbon emissions, material resilience is also a factor. Low-emissions materials which must be replaced often will not necessarily reduce the total emissions of the project. A higher-emission material may be chosen if the emissions of the material are less than the total emissions for replacements of the lower-emissions material. For example, a material with a ten year life span which has an embodied energy of 100 tons CO_2 will be chosen over a material with a 5 year life span which has an embodied energy of 60 tons of CO_2.

Logistics, Site Material Control, and Automated Material Systems

The sections of this plan will be developed based on final site location and funding approval from Clemson University. These sections will include logistics measures, material control on site, and any automated systems necessary. The Logistics section will take into account student traffic in and around Clemson University, which will influence available delivery times and routes, as well as desirable construction times. For example, the summer session at the University is better for building projects, where student traffic during class change and extracurricular events will have less impact on delivery vehicles. The Site Material Control section will include the location and set-up of lay-down area and availability of on-site materials storage space. An appropriate automated material system will be recommended by a University representative if the site location and funding necessitates such a system.

CHAPTER FOUR

LOW CARBON MATERIALS MANAGEMENT GUIDELINES FOR NEW CONSTRUCTION

This paper serves to set forth some standard guides for low carbon materials management, developed through research into carbon emissions of typical building materials. These guidelines are not comprehensive, but seek to promote sustainable materials choice habits in project engineers. Sustainable habits can decrease the environmental and economic impacts of new construction projects.

Background

All construction projects have significant environmental impacts. In recent years there has been a focus in the industry to build “sustainably” – taking into account the environmental, societal, and economic impacts of the project, and decreasing those impacts where possible. In the 1980s, the Construction Industry Institute published a guide for building a materials management plan, which was a way for project managers to reduce surplus, increase productivity, and improve supplier performance, among other things, simply by planning material selection and storage and keeping track of inventory with a computer program [7]. Research following the implementation of materials management plan suggested several benefits, including those listed above; however, almost all of these benefits were focused on reducing the economic impact of the project. Of course, reducing economic impacts are crucial to contractors and project owners;

however, economic impacts are not the only point of sustainability for a project. Reducing carbon emissions for a project will reduce the environmental impact, and can be achieved through little up-front cost, simply by changing materials selections.

Guidelines

Consideration of several key points can serve to reduce the economic and environmental impact of the project at its outset. These points are guidelines developed through the analysis of carbon emissions from various typical building materials. Project managers who are looking to build sustainably without spending money on active technologies which have several-year payback periods can look through these guidelines and plan projects accordingly, achieving a measure of sustainability with little or no up-front cost.

Guideline 1: Material choices are key.

An analysis of the carbon emissions for typical construction materials provides a base for engineers who would like to reduce the carbon emissions of projects. With a detailed materials take-off and carbon emission data for typical materials, an engineer can determine those areas of the project with the highest impact. For example, for the Clemson Net Zero Energy house, the flooring had the largest impact on the total carbon emissions of the project, based on the categories studied (See Table 4.1). Therefore, choosing a flooring material with less unit carbon emissions than carpeting has the potential to drastically reduce the carbon emissions of the whole project. Changing only this one category also potentially minimizes the cost effect of using sustainable materials.

Table 4.1, NZEH Materials Selection, Typical

Materials	**Sub-category**	**Amount [m^2, m^3]**	**Total CO_2 [kg]**	**Total CO_2 [kg]**
Foundation	PC Concrete	14.196	2,081	
Insulation	Fiberglass Batt, R-7	131.889	119	
Interior Walls	Treated Wood, generic	131.889	435	
Exterior Walls	Brick & Mortar	295.989	13,379	42,093
Flooring	Carpet with felt/foam underlay	199.277	23,913	
Roofing	Asphalt Shingles	139.726	2,166	

Sometimes, the materials we think will have the largest impact on the carbon emissions of a project, like the foundation or exterior walls, have quite small impacts compared to other areas, like flooring selection, which we may not even consider in our initial design work. A complete materials take-off, with carbon emissions comparisons, can help us choose materials wisely. Choosing wood products over more involved manufacturing processes, like hardwood over carpeting or wood framing over steel framing, can have a deceptively large impact, provided the structure involved can be adapted accordingly. Similarly, choosing a higher R-value insulation may or may not have a great impact on embodied carbon emissions, although it will affect the energy performance of the building. Obviously, for large commercial or industrial projects, choosing hardwood flooring may be impractical for a variety of reasons. However, information is available from many sources (BEES, BRE, Athena, etc.) regarding the carbon emissions of typical construction materials. A fairly small amount of research at the beginning of a project can make a huge difference over the life of the building.

Guideline 2: Consider local materials.

The distance a material travels from its raw state to its final consumer affects the carbon emissions embodied in that material. Using materials whose entire life cycle is closer to a project site therefore reduces the embodied energy of the project. Table 2.8 shows carbon emissions data for materials ordered from within 500 miles and within 50 miles of Clemson University, respectively. The table illustrates the difference in carbon emissions achievable through local ordering. If materials are available locally for the NZEH, the carbon emissions savings is as high as 6,348 kg CO_2.

The energy used in transporting materials can sometimes be the highest contributor to their embodied energy. Transporting raw materials to processing plants, processed materials to manufactures, goods to retailers and then consumers, is costly to the environment. Materials which are produced locally will, by necessity, have a lower environmental impact than those same materials produced elsewhere. If a project is being constructed near a lumber yard, or quarry, or other material manufacturing center, using that material is carbon efficient, as well as sometimes more inexpensive, pending shipping costs. Buying locally also has an effect on the *societal* impact of a project, because it serves to involve the community surrounding the project, giving them a feeling of ownership and pride over the new structure.

Guideline 3: Planning is everything.

Even if a project owner decides not to change materials based on carbon emissions data, proper planning for materials management can save costs and surplus and can increase labor productivity. Several of these benefits will indirectly reduce the environmental impacts of a project. Some benefits will directly reduce not only the environmental but also the economic impacts of the project.

Guideline 4: Materials carbon emissions aren't everything.

Throughout this study, increasing project sustainability has been defined as decreasing carbon emissions for the project. Although more easily quantified, carbon emissions are not the only consideration necessary for sustainable development. Building and material resilience, societal impact, and cost will also affect the sustainability of a building. For the Clemson Net Zero Energy House, funding availability and amounts will likely have a larger impact on materials selection than carbon emissions data. In some cases, choosing materials with low carbon emissions may be cost prohibitive, or may reduce the overall resilience of a building. Consideration must be taken on the part of the project engineer to weigh the importance of each of these factors in order to maximize potential sustainability.

REFERENCES

[1] "Our Common Future: From One Earth to One World - A/42/427 Annex, Overview - UN Documents: Gathering a Body of Global Agreements." *UN Documents: Gathering a Body of Global Agreements. Hyperlinked Collection of More than 500 Key United Nations Documents*. Web. 18 April 2011. <http://www.un-documents.net/ocf-ov.htm>.

[2] Davis, James Allan and Smith, Tom W. *General social surveys, 1972-2008* [machine-readable data file] /Principal Investigator, James A. Davis; Director and Co-Principal Investigator, Tom W. Smith; Co-Principal Investigator, Peter V. Marsden; Sponsored by National Science Foundation. --NORC ed.-- Chicago: National Opinion Research Center [producer]; Storrs, CT: The Roper Center for Public Opinion Research, University of Connecticut [distributer], 2009. 1 data file [53,043 logical records) + 1 codebook (22,656 pp.). -- (National Data Program for the Social Sciences, no. 18).

[3] Cohen, Steve. “Measuring Public Opinion on Environment and Sustainability: How Conventional Wisdom Gets That Way.” *Observer.com*. The New York Observer, 11 Aug. 2009. Web. 09 Nov. 2010. <http://www.observer.com/2009/measuring-public-opinion-environment-and-sustainability-how-conventional-wisdom-gets-way>

[4] Elkington, John. “Towards the sustainable corporation: win-win-win business strategies for sustainable development.” *California Management Review* 36.2 (1994): 90+. *Academic OneFile*. Web. 15 Nov. 2010.

[5] *Sustainable Materials Management: The Road Ahead*. Rep. no. EPA530R09009. Environmental Protection Agency, June 2009. Web. 9 July 2010. <http://www.epa.gov/wastes/inforesources/pubs/vision2.pdf>.

[6] “Net-Zero Energy Home.” *Sustainability Dictionary*. Ed. Jonathan Mariano. Presidio Graduate School. Web. 09 Nov. 2010. <http://www.sustainabilitydictionary.com/n/netzero_energy_home.php>

[7] Construction Industry Institute (CII). *Procurement and Materials Management: A Guide to Effective Project Execution,* University of Texas at Austin (1999).

[8] *Procurement and Materials Management: a Guide to Effective Project Execution*. Austin, TX: Construction Industry Institute, 1999. Print.

[9] Ramesh, T., Ravi Prakash, and K. K. Shukla. "Life Cycle Energy Analysis of Buildings: An Overview." *Energy and Buildings* 42.10 (2010): 1592-600. *ScienceDirect*. Web. 30 Apr. 2011. <http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V2V-505F9K3-1&_user=10&_coverDate=10%2F31%2F2010&_rdoc=1&_fmt=high&_orig=gateway&_origin=gateway&_sort=d&_docanchor=&view=c&_searchStrId=1747648007&_rerunOrigin=google&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=1ff7d2f97b01a3c094744a8f72a2f1b5&searchtype=a>.

[10] Dixit, Manish K., Jose L. Fernandez-Solis, Sarel Lavy, and Charles H. Culp. "Identification of Parameters for Embodied Energy Measurement: A Literature Review." *Energy and Buildings* 42.8 (2010): 1238-247. *ScienceDirect*. Web. 30 Apr. 2011. <http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V2V-4YG1KXJ-5&_user=10&_coverDate=08%2F31%2F2010&_rdoc=1&_fmt=high&_orig=gateway&_origin=gateway&_sort=d&_docanchor=&view=c&_searchStrId=1747650894&_rerunOrigin=google&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=27a05edc688d2220b8f239b1b3bb7677&searchtype=a>.

[11] *Sustainable Materials Management: The Road Ahead*. Publication no. EPA530-R-09-009. EPA, 2009. Print.

[12] Anderson, Bruce N., and Charles J. Michal. "Passive Solar Design." *Annual Reviews Energy*(1978): 57-100. Web.

[13] Morrissey, J., T. Moore, and R. E. Horne. "Affordable Passive Solar Design in a Temperate Climate: An Experiment in Residential Building Orientation." *Elsevier*. 03 Aug. 2010. Web. 28 Feb. 2011.

[14] Nervegna, Lorina, ed. *Passive Solar Design: Energy Efficiency through Passive Solar Design*. Issue brief no. 1447-199X. Sydney: CCAA, 2003. Cement & Concrete Association of Australia, 09 Apr. 2003. Web. 28 Feb. 2011.

[15] Pless, S., and P. Torcellini. Tech. no. NREL/TP-550-44586. June 2010. Web. 20 Feb. 2011.;Pless, S., and P. Torcellini. Conference paper no.NREL/CP-550-39833. June 2006. Web. 20 Feb. 2011.

[16] Harjula, Henrik. "Outcome of the First OECD Workshop on Sustainable Materials Management."*OECD.org*. Organization for Economic Co-operation and Development, 27 Sept. 2007. Web. <http://www.google.com/search?sourceid=chrome&ie=UTF-8&q=outcome+of+the+first+oecd+workshop+on+sustainable+materials+management>.

[17] "Sustainable Design Program." *GSA.gov*. US General Services Administration. Web. 25 Apr. 2011. <http://www.gsa.gov/portal/content/104462>; *Sustainable Building Policy*. Clemson, SC: Clemson University Facilities, 14 Mar. 2005. Pdf.

[18] *LEED 2009 for New Construction and Major Renovations*. Publication. Washington, D.C.: USGBC, 2009. Print.

[19] *Sustainable Materials Management: The Road Ahead*. Rep. no. EPA530R09009. Environmental Protection Agency, June 2009. Web. 9 July 2010. <http://www.epa.gov/wastes/inforesources/pubs/vision2.pdf>.

[20] Ashby, Michael F. *Materials and the Environment Eco-informed Material Choice*. Amsterdam: Butterworth-Heinemann, 2009. Print.

[21] BEES. "BEES Online Life Cycle Analysis for Building Products." BEES. *National Institute of Standards and Technology.* Web. <http://ws680.nist.gov/Bees/(A(zgv7rg9NzQEkAAAANmY5YjkzNzUtMzExOC00MGYxLTk2MDQtNDU5NzIwMzAyZDI59hxKFDwnBcUK4AXj9Lvq-UP5oAw1))/AnalysisParametersBuildingProds.aspx>.

[22] BRE. "BRE Green Guide." BRE Group: Green Guide to Specification. Web. <http://www.bre.co.uk/greenguide/podpage.jsp?id=2126>.

[23] Atkinson, Aimee. "How Much CO2 Is Created By..." *GE Data Visualization*. General Electric. Web. <http://visualization.geblogs.com/visualization/co2/>.

[24] Infographs created by Gabrielle Conlon.

[25] Prices from www.lowes.com, www.builddirect.com, www.grainger.com, and www.spheralsolar.com.